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BRIEFER ARTICLES.

NOTE ON THE RELATION BETWEEN GROWTH OF ROOTS AND OF TOPS IN WHEAT.

CONTRIBUTIONS FROM THE HULL BOTANICAL LABORATORY. LXXXI.

STUDIES in the experimental morphology of plants have dealt mainly with the subaerial portions, comparatively little attention having been paid to variations in the growth of roots. Thus the literature of the subject is very meager. Several authors, especially MOELLER,[1] DETMER,[2] PERSEKE,[3] MER,[4] GAIN,[5] and FREIDENFELT,[6] have studied the relation of water to the growth of these organs, with the general result that in water itself they grow longer and thinner, with fewer branches and root hairs than are observed in moist soils. Curiously enough, in soils which are too dry for optimum growth, the response is very similar. The roots are long and slender and possess few branches excepting near their tips, which lie, of course, in moister soil.

The only observation on the relation of root growth to that of tops, with which the writer is acquainted, is that of MOELLER, to the effect that in a series of nutrient solutions, of concentrations ranging from 1.0 to 0.05 parts per thousand, the actual weight of roots produced varies generally with the concentration, but that the ratio of weight of roots to that of tops is much larger in the most dilute solution than in any of the others.

A number of experiments have suggested to the author that the accelerating or retarding effect of the soil upon plant growth may often be due primarily to a response of the roots themselves, and that the ordinarily observed effect upon the tops may be due to the nature of the roots rather than to that of the soil directly. This question deserves thorough study; the results to be given here cover only a very small portion of the field.

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[1] MOELLER, H., Beiträge zur Kenntniss der Verzwergung. Landw. Jahrb. **13**: 167-173. 1884.

[2] DETMER, W., Ueber den Einfluss äusserer Verhältnisse auf die Wurzelentwickelung. Landw. Versuchst. **15**: 107–113. 1872.

[3] PERSEKE, K., Ueber die Formveränderungen der Wurzel in Erde und Wasser. Leipzig. 1877.

[4] MER, E. De l'influence des milieux sur la structure des racines. Comptes Rend. **88**: 1277–1280. 1879.

———Recherches expérimentales sur les conditions de développement des poils radicaux. *Ibid.* 665–668.

———Des modifications de structure et de forme qu'éprouvent les racines suivant les milieux où elles végètent. Assoc. Franc. pour l'avance. sc. Compt. rend. de la 9^e^ session. Rheims. 1880.

[5] GAIN, E., Rôle physiologique de l'eau dans la végétation. Paris. 1895.

[6] FREIDENFELT, F., Studien über die Wurzeln kraütiger Pflanzen. I. Ueber die Formbildung der Wurzel vom biologischen Gesichtspunkte. Flora **91**: 115–208. 1902.

This work was carried on at the laboratories of the Bureau of Soils of the U. S. Department of Agriculture, Washington, D. C. The plant used was the Russian variety of wheat known as "Chul." The plants were grown directly from the seed in paraffined wire baskets of the form described by WHITNEY and CAMERON.[7] As these authors have already pointed out, such baskets possess the advantage over pots of producing a root system uniformly distributed throughout the soil mass, rather than the accumulation of roots on the inner surface of the vessel which occurs in the case of ordinary pots.

The studies to be discussed in this paper were made upon the roots developed in the first six series described in the author's previous publication[8] on the growth of tops, and in similar cultures. The medium used was a very poor soil from Takoma Park, Md., and the same soil with varying amounts of fermented stable manure added thereto.[9] The cultures of any series were placed side by side in a greenhouse, the amount of water in all the baskets being kept practically uniform by weighing at intervals of one or two days and adding the amount of water which was found to have been lost by transpiration. It is thus seen that the different cultures were all subjected to the same conditions excepting those which depend upon the treatment of the soil.

Series I of the paper on growth of tops[10] will serve as an example; the results of all the series are in accurate agreement. The soils and culture numbers were as follows:

Basket Number	1	2	3	4	5	6	7	8
Soil	Takoma Soil untreated	Do.+ 5000 p.p.m.[11] manure	Do.+ 10,000 p.p.m. manure	Do.+ 15,000 p.p.m. manure	Do.+ 20,000 p.p.m. manure	Do.+ 30,000 p.p.m. manure	Do.+ 40,000 p.p.m. manure	Do.+ 50,000 p.p.m. manure

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[7] WHITNEY, M. and CAMERON, F. K., Investigations in soil fertility. U. S. Dept. Agric., Bureau of Soils, Bull. 23. 1904.

[8] LIVINGSTON, B. E., Relation of transpiration to growth in wheat. BOT. GAZETTE 40:178–195. *figs. 21.* 1905.

[9] For a description of this soil and a discussion of its properties, see LIVINGSTON, B. E., BRITTON, J. C., and REID, F. R., Studies on the properties of a sterile soil. U. S. Dept. Agric., Bureau of Soils, Bull. 28. 1905.

[10] A photograph of the tops and data for their growth are given in that paper.

[11] The abbreviation p. p. m. is used to denote parts per million by weight of air dry soil.

At the end of the experiment, which lasted seventeen days, the soil masses were taken from the baskets and the roots removed from them with as little injury to the latter as possible. The fresh roots thus prepared are shown in *fig. 1*. The numbers correspond to the culture numbers given above. It is at once evident that the root system increases in amount throughout the series. Closer observation shows that this is due mainly to differences in the relative number and length of secondary roots and succeeding branches; the primary roots are of the same number in culture 8 as in culture 1. They are somewhat longer and more slender in culture 8.

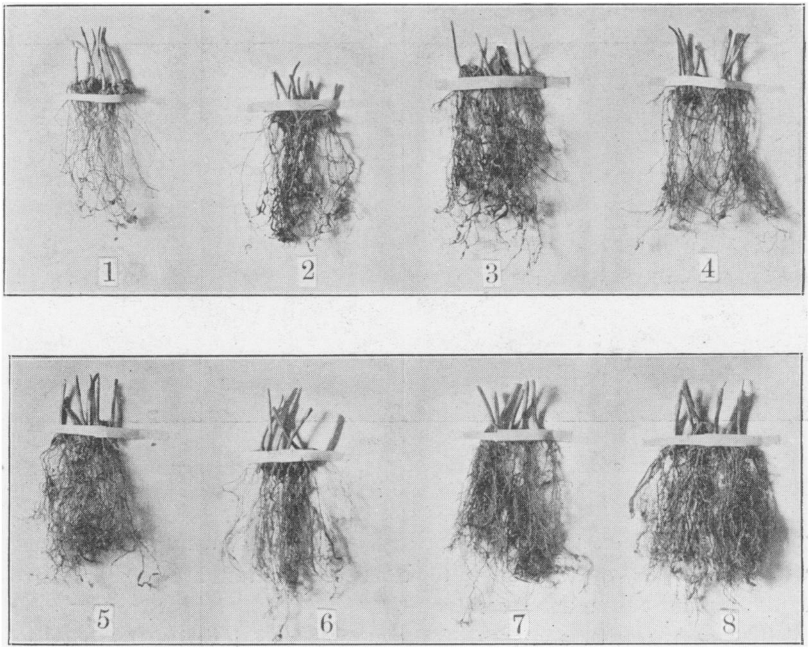

FIG. 1.—Roots from a series of wheat cultures grown in Takoma soil untreated and in the same with addition of 5000 p.p.m. to 50,000 p.p.m. of stable manure.

Photographs of single root systems from a similar series are shown in *figs. 2–5*, which bring out the last point more clearly than *fig. 1*. In *fig. 2*, which represents the roots from natural Takoma soil, very few branches are to be seen, and these are exceedingly short; practically the whole root system consists of the primary roots, with a few adventitious roots developed at the extreme base of the stem shortly after germination. *Fig. 3* shows roots from a soil containing 5000 parts per million of manure.

A very slight increase in number and length of branches is to be observed. *Fig. 4*, from a soil containing 10,000 parts per million of manure, shows numerous well-developed branches, while from a soil with 40,000 parts per million of manure, as shown in *fig. 5*, the branches have increased so markedly in number and extent as to make up by far the greater part of the system.

From these facts it is seen that, for this series of soils the variation in growth of tops is correlated with the number and length of lateral roots. The water content of all the soils was the same, so that the variations in growth cannot be related to this factor; therefore they must be connected with some unknown condition in the soil itself, a condition which is related to the amount of manure present.

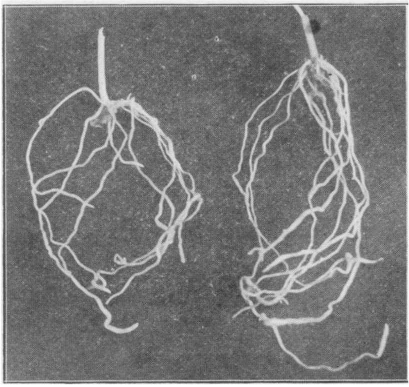

FIG. 2.—Wheat roots grown in Takoma soil untreated.

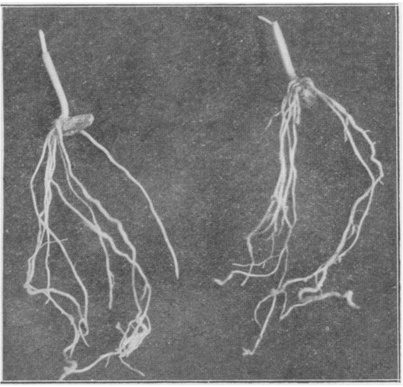

FIG. 3.—Roots grown in Takoma soil with 5000 p.p.m. manure.

The comparative anatomy of these roots was investigated, both by hand and paraffin sections, with the result that in the poor soils the main roots have a strong tendency to swell by direct enlargement of the cortical cells, without increase in the number of these cells, while in the better soils this tendency is not nearly so marked. Very old wheat roots from autumm stubble in the field show this balloon-like enlargement of the cortical cells to a still greater degree. This is apparently a phenomenon of age, suggesting that roots in the poor soils age more rapidly than in the better ones. It was also found that the zone of root hairs, which normally has its lower limit 5–10$^{\mathrm{mm}}$ from the root apex, extends in the poor soils to within 1–3$^{\mathrm{mm}}$ of the tip. The outgrowth of root hairs from the piliferous layer may also be related to the age of the cells; as is well known, these organs normally appear only after the cells from which they arise have passed through their period of most rapid growth.

It would seem that the poor soil, by inhibiting branch growth and causing the enlargement of cortical cells, may render the root system unable to carry on an adequate amount of absorption for normal growth, and that this fact may be the main clue to an explanation of the stunted tops in such cases. That the inadequacy of the stunted roots is in regard to the water supply rather than to that of salts, is indicated by the fact that in distilled water, for the first two or three weeks, a better growth of tops is obtained than in the natural Takoma soil.

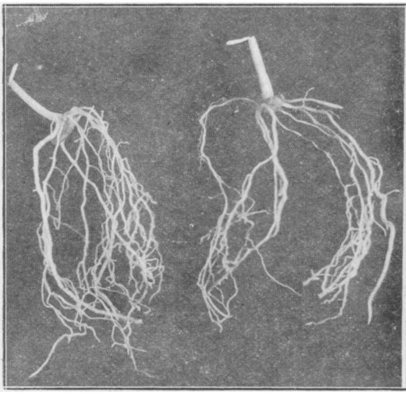

FIG. 4.—Roots grown in Takoma soil with 10,000 p.p.m. manure.

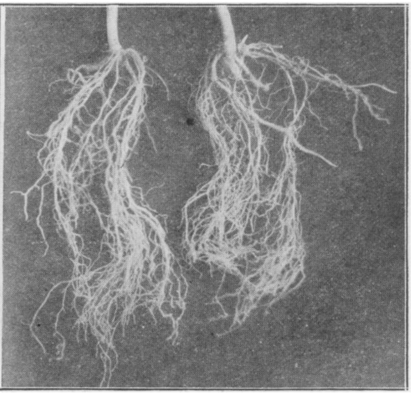

FIG. 5.—Roots grown in Takoma soil with 40,000 p.p.m. manure.

Determination of the relation of the dry weight of the root system to the nature of the soil was deemed advisable, but a number of tests yielded only negative results. The dry weight of the complete system was found to be practically the same from all of the soils. The variations were always irregular. This may, of course, be partially due to the fact that, while it is manifestly impossible to obtain anything like the entire root system of one of the better cultures (owing to the extreme fineness of the branches and their adhesion to the soil particles), yet from the poorer cultures, where branches are short and few, a much larger part of the system is obtainable.—BURTON EDWARD LIVINGSTON, *The University of Chicago, March 5, 1905.*